Introductions, Binary

Introduction to Computer Systems, Fall 2022

Instructor: Travis McGaha

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Lecture Outline

- **Introduction & Logistics**
  - **Course Overview**
  - **Assignments & Exams**
  - **Policies**
- Binary
  - Conversions
  - Hexadecimal
  - ASCII
  - Length Constraints

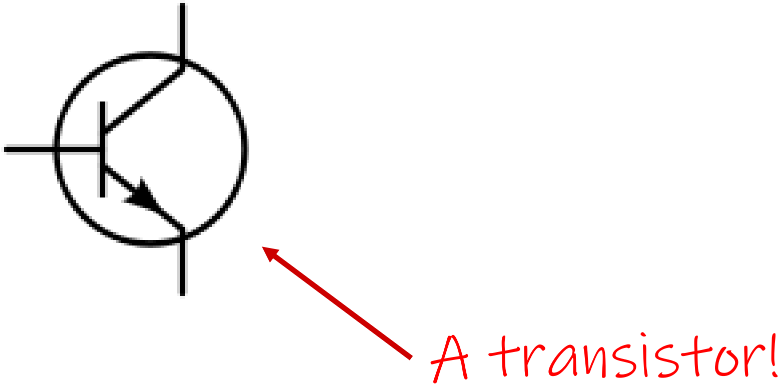
Instructor: Travis McGaha

- UPenn CIS faculty member since… August 2021
  - Currently my third semester at UPenn
  - First Semester Solo with CIS 2400

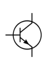
- I have COVID :))))))))))))))))))
  - My brain is not always there

- More on my personal website: https://www.cis.upenn.edu/~tqmcgaha/

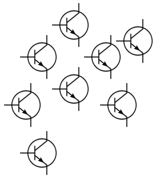
Course Overview: First Half



Course Overview: First Half

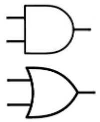


Course Overview: First Half

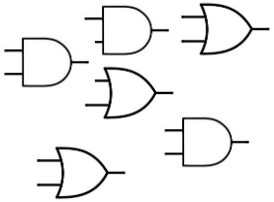


Course Overview: First Half

Logic Gates



Course Overview: First Half



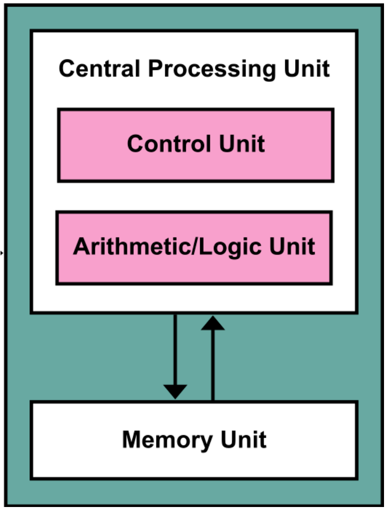
Course Overview: First Half

Adder

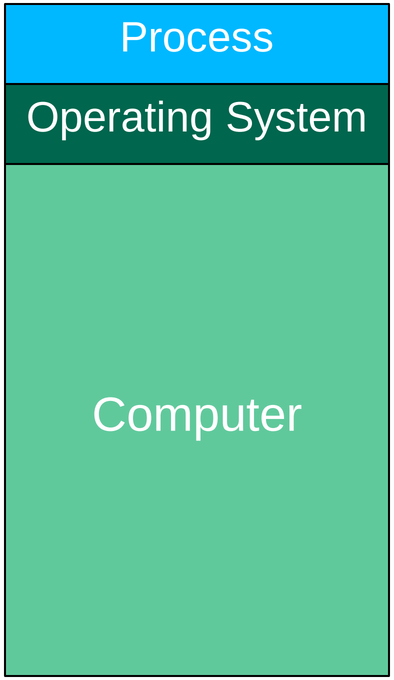
Mux/Demux

Latch/Flip-Flop

Course Overview: First Half



Course Overview: First Half



Course Overview: Second Half

```c
#include <stdio.h>

int main() {
  printf("hello world!\n");
}
```

C Programming ☺

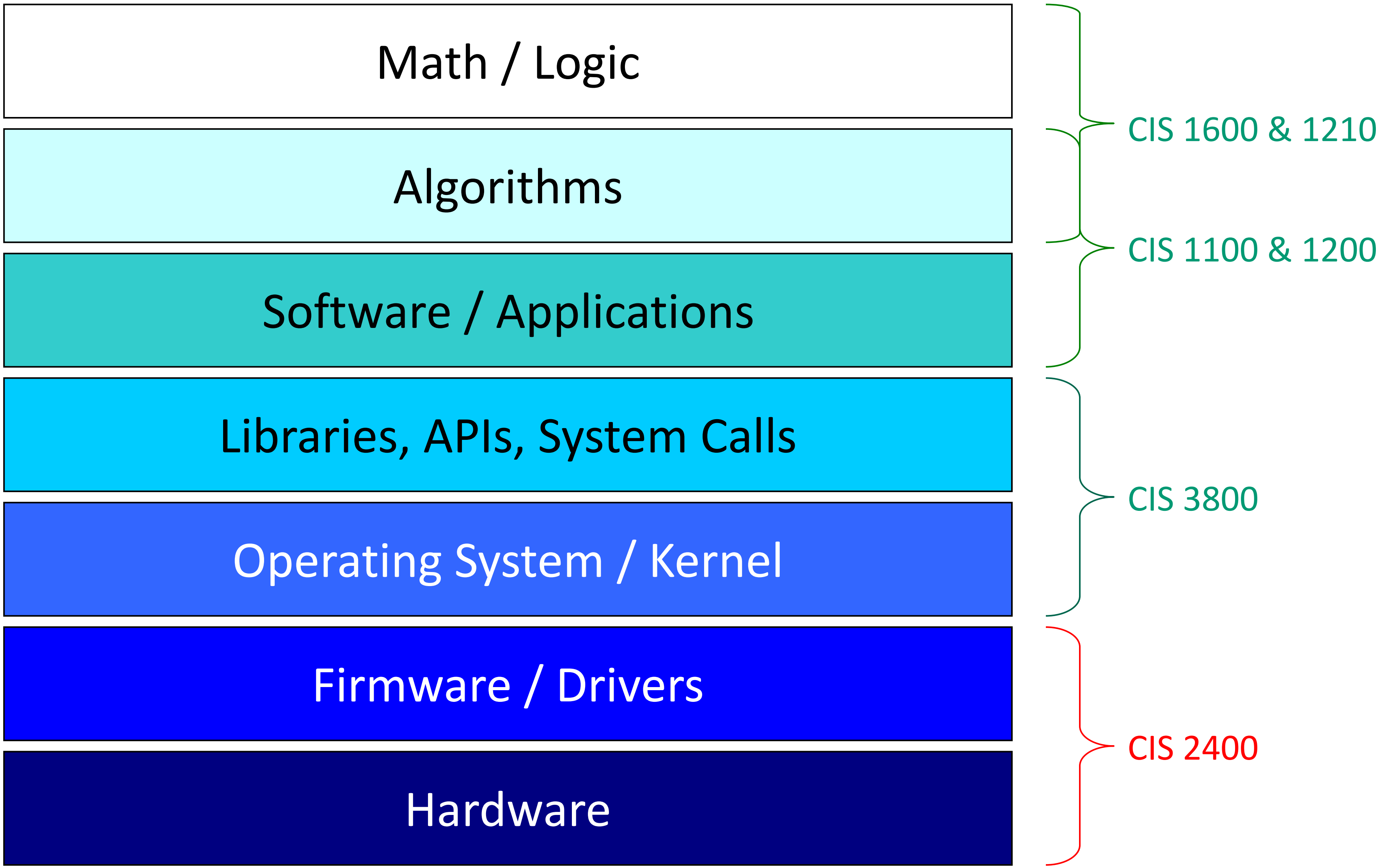
```
.LC0:
        .string "hello world!"
        .text
        .globl  main
        .type   main, @function
main:
.LFB0:
        .cfi_startproc
        pushq   %rbp
        .cfi_def_cfa_offset 16
        .cfi_offset 6, -16
        movq    %rsp, %rbp
```

Assembly Translation

```
00000200: 52e5 7464 0400 0000 b80d 0000 0000 0000
00000210: b80d 2000 0000 0000 b80d 2000 0000 0000
00000220: 4802 0000 0000 0000 4802 0000 0000 0000
00000230: 0100 0000 0000 0000 2f6c 6962 3634 2f6c
00000240: 642d 6c69 6e75 782d 7838 362d 3634 2e73
00000250: 6f2e 3200 0400 0000 1000 0000 0100 0000
00000260: 474e 5500 0000 0000 0300 0000 0200 0000
```

Machine-runnable code

Course Overview



Learning Objectives

- To leave the class with a better understanding of:
  - How a computer “really” works and runs your code
  - What a computer is good at, how to exploit its strengths
  - How modern hardware changes can affect software
  - C programming ☺

- Topics list/schedule can be found on the course website

Prerequisites

- Course Prerequisites:
  - CIS 110/CIS 120

- What you should know already:
  - Vague familiarity with how a program executes
  - Java programming
  - How to write & design large open-ended programs from scratch

Disclaimer

- This is a digest,
- **READ THE WEBSITE**
  - https://www.seas.upenn.edu/~cis2400/current/
- **READ THE SYLLABUS**
  - https://www.seas.upenn.edu/~cis2400/22fa/documents/syllabus

Course Components pt. 1

- Lectures (26)
  - Introduces concepts, slides & recordings available
  - In lecture polling. Polls remain open until the next lecture
- Sections (~10)
  - Reiterates lecture content, lecture clarifications, assignment & exam preparation. Optional, details TBD
- Homework Assignments (12)
  - Due every week
  - Most are programming
  - Very flexible on-request late policy

Course Components pt. 2

- Participation (lots)
  - Lecture polls, Section participation, Weekly Check-in quizzes
- Exams (2)
  - Two in-person exams
  - Midterm will be October 26^{th} “In class”
  - Final will be the week of finals (more details later)
- Textbook (0)
  - No official textbook, but some suggested on course site

Course Infrastructure

- Canvas
  - Grades, surveys, quizzes, Lecture recordings
- Course Website
  - Hosts almost all course content. Syllabus, slides, assignment specifications, course schedule….
  - https://www.seas.upenn.edu/~cis2400/22fa/
- Gradescope
  - Used for most homework turn ins
- Poll Everywhere
  - Used for lecture polls
- Ed
  - Course discussion board

Course Policies

- HW Late Policy
  - Late days given on request
    - (Request usually granted)
  - No cap on the number of late days per assignment
    - More than 3 on an assignment requires approval from Travis
    - Written HWs will not get more than 3 days late.

- Midterm Clobber Policy
  - Final is cumulative
  - If you do better on the “midterm section” of the final, your midterm grade can be replaced.

Getting Help

- Ed
  - Announcements will be made through here
  - Ask and answer questions
  - Sign up if you haven't already!

- Office Hours:
  - Can be found on calendar on top of course website
  - Starts.... soon? (waiting on room reservations)

- 1-on-1's:
  - Can schedule 1-on-1's with Travis
  - Should attend OH and use Ed when possible, but this is an option for when OH and Ed can't meet your needs

We Care

- It is very important that you succeed in CIS 2400 and have a positive experience.
  - Please reach out to course staff if something comes up and you need help
  - Please reach out to course staff if you feel disrespected or uncomfortable by anything

- PLEASE DO NOT CHEAT OR VIOLATE ACADEMIC INTEGRITY
  - We know that things can be tough, but please reach out if you feel tempted. We want to help you succeed
  - Read more on academic integrity in the syllabus

Any questions on anything?

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Lecture Outline

- Introduction & Logistics
  - Course Overview
  - Assignments & Exams
  - Policies
- **Binary**
  - **Conversions**
  - **Hexadecimal**
  - **ASCII**
  - **Length Constraints**

Base 10 (Decimal Numbers)

- Humans typically process numbers in base 10
  - Each digit can represent 10 different values
  - Each digit is weighted by its position

- Example: 382

$$(3 * 10^2) \quad + \quad (8 * 10^1) \quad + \quad (2 * 10^0)$$

Base 2 (Binary Numbers)

- Computers typically process numbers in base 2
  - Each "bit" can represent 2 different values (1 or 0)
  - Each "bit" is weighted by its position

- Example: 101

$$(1 * 2^2) \quad + \quad (0 * 2^1) \quad + \quad (1 * 2^0)$$

$$4 \quad + \quad 0 \quad + \quad 1$$

$$5$$

To note that a value is in base 2, a prefix '**`0b`**' is often used

Example: **`0b101`**

Practice

- What is 0b10110 in base 10?

Poll Everywhere

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- What is 0b10110 in base 10?

A. 6

B. 22

C. 16

D. 38

E. I'm not sure

Poll Everywhere

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- What is 0b10110 in base 10?

A. 6

B. 22

C. 16

D. 44

E. I'm not sure

0b10110

$(1 * 2^4) + (0 * 2^3) + (1 * 2^2) + (1 * 2^1) + (0 * 2^0)$

$16 + 0 + 4 + 2 + 0$

$16 + 4 + 2$

22

Decimal to Binary Conversion: Powers of 2

- Algorithm:
  - Subtract the largest power of two <= number
  - Put a one in the corresponding bit position
  - Repeat until number is 0

- Example: 104
  - 104 - 64 = 40 — 64 is 2^6, so bit 6 is a ‘1’
  - 40 - 32 = 8 — 32 is 2^5, so bit 5 is a ‘1’
  - 8 – 8 = 0 — 8 is 2^3, so bit 3 is a ‘1’
  - 104 = 0b1101000

n	2^n
0	1
1	2
2	4
3	8
4	16
5	32
6	64
7	128
8	256
9	512
10	1024

Decimal to Binary Conversion: Division

- Algorithm:
  - Divide by two – remainder will be the next smallest bit
  - Keep dividing until answer is 0

- Example: 104
  - 104 / 2 = 52 r 0 bit 0 is 0
  - 52 / 2 = 26 r 0 bit 1 is 0
  - 26 / 2 = 13 r 0 bit 2 is 0
  - 13 / 2 = 6 r 1 bit 3 is 1
  - 6 / 2 = 3 r 0 bit 4 is 0
  - 3 / 2 = 1 r 1 bit 5 is 1
  - 1 / 2 = 0 r 1 bit 6 is 1
  - 104 = 0b1101000

Poll Everywhere

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- What is 99 in binary?

A. 0b111111

B. 0b110111

C. 0b1011111

D. 0b1100011

E. I'm not sure

n	2^n
0	1
1	2
2	4
3	8
4	16
5	32
6	64
7	128
8	256
9	512
10	1024

Poll Everywhere

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- What is 99 in binary?

A. 0b111111

B. 0b110111

C. 0b1011111

D. 0b1100011

E. I'm not sure

99 – 64 = 35, bit 6 is 1

35 – 32 = 3, bit 5 is 1

3 – 2 = 1, bit 1 is 1

1 – 1 = 0, bit 0 is 1

n	2^n
0	1
1	2
2	4
3	8
4	16
5	32
6	64
7	128
8	256
9	512
10	1024

Hexadecimal

- Base 16 representation of numbers
- Allows us to represent binary with fewer characters
- Prefixes to identify the base
  - 0b11110011 == 0xF3
    ^ **b**inary ^ he**x**
- Hexadecimal will be useful for later homework assignments

Decimal	Binary	Hex
0	0000	0x0
1	0001	0x1
2	0010	0x2
3	0011	0x3
4	0100	0x4
5	0101	0x5
6	0110	0x6
7	0111	0x7
8	1000	0x8
9	1001	0x9
10	1010	0xA
11	1011	0xB
12	1100	0xC
13	1101	0xD
14	1110	0xE
15	1111	0xF

Poll Everywhere

pollev.com/tqm

- What is 0b110101110100 in hex?

A. 0xD74

B. 0x6BA

C. 0x45D

D. 0x2EB

E. I'm not sure

Decimal	Binary	Hex
0	0000	0x0
1	0001	0x1
2	0010	0x2
3	0011	0x3
4	0100	0x4
5	0101	0x5
6	0110	0x6
7	0111	0x7
8	1000	0x8
9	1001	0x9
10	1010	0xA
11	1011	0xB
12	1100	0xC
13	1101	0xD
14	1110	0xE
15	1111	0xF

Poll Everywhere

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- What is 0b110101110100 in hex?

A. 0xD74

B. 0x6BA

C. 0x45D

D. 0x2EB

E. I'm not sure

0b110101110100

0xD 0x7 0x4

Decimal	Binary	Hex
0	0000	0x0
1	0001	0x1
2	0010	0x2
3	0011	0x3
4	0100	0x4
5	0101	0x5
6	0110	0x6
7	0111	0x7
8	1000	0x8
9	1001	0x9
10	1010	0xA
11	1011	0xB
12	1100	0xC
13	1101	0xD
14	1110	0xE
15	1111	0xF

Hex Spelling

- **`0xDEADC0DE`**
- **`0xDEADBEEF`**
- **`0xBO1DFACE`**
- **`0xBADA55`**
- **`0xCAFEF00D`**
- **`0xF00`**

Encoding

- We can represent more than just numbers with bits
  - We just need an agreed upon encoding

- Decimal Numbers
  - 0 → **0x00**, 1 → **0x01**, … , 240 → **0xF0** …

- Characters
  - A → **0x41**, B → **0x42**, C → **0x43**, …

- Colors
  - → 0x281EF2, → 0x990000

The Meaning of Bits

- *A sequence of bits can have many meanings!*

- Consider the hex sequence 0x4E6F21
  - Common interpretations include:
  - The decimal number 5140257
  - The characters “No!”
  - The background color of this slide
  - The real number 7.203034×10^{-39}

- A series of bits can also be code!

- It is up to the program/programmer to decide how to ***interpret*** the sequence of bits

ASCII

- We can encode binary values to represent characters

ASCII TABLE

Decimal	Hex	Char	Decimal	Hex	Char	Decimal	Hex	Char	Decimal	Hex	Char
0	0	[NULL]	32	20	[SPACE]	64	40	@	96	60	`
1	1	[START OF HEADING]	33	21	!	65	41	A	97	61	a
2	2	[START OF TEXT]	34	22	"	66	42	B	98	62	b
3	3	[END OF TEXT]	35	23	#	67	43	C	99	63	c
4	4	[END OF TRANSMISSION]	36	24	$	68	44	D	100	64	d
5	5	[ENQUIRY]	37	25	%	69	45	E	101	65	e
6	6	[ACKNOWLEDGE]	38	26	&	70	46	F	102	66	f
7	7	[BELL]	39	27	'	71	47	G	103	67	g
8	8	[BACKSPACE]	40	28	(	72	48	H	104	68	h
9	9	[HORIZONTAL TAB]	41	29	)	73	49	I	105	69	i
10	A	[LINE FEED]	42	2A	*	74	4A	J	106	6A	j
11	B	[VERTICAL TAB]	43	2B	+	75	4B	K	107	6B	k
12	C	[FORM FEED]	44	2C	,	76	4C	L	108	6C	l
13	D	[CARRIAGE RETURN]	45	2D	-	77	4D	M	109	6D	m
14	E	[SHIFT OUT]	46	2E	.	78	4E	N	110	6E	n
15	F	[SHIFT IN]	47	2F	/	79	4F	O	111	6F	o
16	10	[DATA LINK ESCAPE]	48	30	0	80	50	P	112	70	p
17	11	[DEVICE CONTROL 1]	49	31	1	81	51	Q	113	71	q
18	12	[DEVICE CONTROL 2]	50	32	2	82	52	R	114	72	r
19	13	[DEVICE CONTROL 3]	51	33	3	83	53	S	115	73	s
20	14	[DEVICE CONTROL 4]	52	34	4	84	54	T	116	74	t
21	15	[NEGATIVE ACKNOWLEDGE]	53	35	5	85	55	U	117	75	u
22	16	[SYNCHRONOUS IDLE]	54	36	6	86	56	V	118	76	v
23	17	[ENG OF TRANS. BLOCK]	55	37	7	87	57	W	119	77	w
24	18	[CANCEL]	56	38	8	88	58	X	120	78	x
25	19	[END OF MEDIUM]	57	39	9	89	59	Y	121	79	y
26	1A	[SUBSTITUTE]	58	3A	:	90	5A	Z	122	7A	z
27	1B	[ESCAPE]	59	3B	;	91	5B	[	123	7B	{
28	1C	[FILE SEPARATOR]	60	3C	<	92	5C	\	124	7C	|
29	1D	[GROUP SEPARATOR]	61	3D	=	93	5D	]	125	7D	}
30	1E	[RECORD SEPARATOR]	62	3E	>	94	5E	^	126	7E	~
31	1F	[UNIT SEPARATOR]	63	3F	?	95	5F	_	127	7F	[DEL]

ASCII Design

- ASCII:
  American Standard Code for Information Interchange

- Designed to communicate American letters, numbers, and some control signals efficiently
  - Used only 7 bits to minimize number of bits that need to be communicated
  - Other languages not considered

Unicode

- Unicode Standard UTF-8 is an alternate text encoding
  - Uses between 8 and 32 bits for each “character”
  - Characters include more than just English
  - Characters include emojis

- Unicode table is a lot longer: https://unicode-table.com/en/

Aside: Length Terminology

- Bit:
  - a binary "digit", either a 1 or a 0
- Byte:
  - 8 bits
  - E.g., 0b11110111 or 0xF7
- Nibble:
  - 4 bits
  - E.g., 0b1011 or 0xB

Data Lengths

- Computers are physical machines
  - there is a limit to how many bytes we can store

- In C:
  - `int`'s are usually 4 bytes
    - 4 bytes = 32 bits → 2^{32} different values
    - 2^{32} = 4,294,967,296
  - `char`'s are usually 1 byte
    - 1 byte = 8 bits → 2^{8} different values
    - 2^{8} = 256

Lecture Take-aways

- Bits are the “atom” of data for computers

- We can represent anything in binary by using different encodings!
  - Numbers, colors, characters, emojis, code, etc..

- Our encodings/data is limited due to finite bits
  - (More on this next time)